HARTRICK

Analyses and Properties of Boiler Waters and Boiler Scales

Chemistry

B. S.

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Analyses and Properties of Boiler Waters and Boiler Scales

BY GUY RUSSELL HARTRICK

THESIS

FOR THE

Degree of Bachelor of Science in Chemistry

IN THE

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THE ANALYSIS AND PROPERTIES OF BOILER WATERS AND BOILER SCALES.

To understand the chemical composition of subterranean waters we must first inquire into the geological constitution of the earth.

The solid earth consists of material which exists in two different forms, soils and rocks; the former being generally on the surface and the latter underneath forming the hard unyielding foundation to the superstructure. These are of particular interest to us because they are directly responsible for the mineral inpurities found in waters.

Ninety seven per cent. of the rocks composing the earths crust consist of the elements, oxygen, aluminium, calcium, silicon, magnesium, potassium, sodium, and iron. These unite with each other, or with a few of the rarer elements to form the rocks.

Quartz composed chiefly of oxygen and silicon constitutes not only the principal mass of most rock formations, but exists in several other forms, as quartzite and quartz sand. It forms transparent crystals so hard as to scratch glass.

Feldspar is next to quartz the most abundant mineral in nature. It is a compound of silica with aluminium and alkalies or lime. The different varieties of feldspar are: orthoclase or soda lime feldsparl albite or soda feldspar; and labradorite or lime soda

46727

feldspar.

Calcite is a widely distributed rock and in its different conditions forms marble, chalk and other varieties of limestone.

Dolomite consists of a union of the carbonates of magnesium and calcium in different proportions. It is generally crystalline.

Gypsum, or hydrous sulphate of calcium resembles dolomite somewhat yet is more abundant and more soluble. It exists in most soils and when boiled until it loses its water of crystallization it becomes "Plaster of Paris" of commerce.

Common salt or sodium chloride, is one of the most abundant of all minerals. It exists not only in the solid rock form but also is found in great quantities in mineral springs and forms the chief mass of the saline constituents of salt water.

Iron minerals play an important part in the composition of rocks and the resulting soils. The principal ores are the carbonate, oxides and sulphide.

Nitrates occur to some extent native, for example the nitrates of calcium, magnesium, potassium and sodium. Alkali nitrates are found in rivers, spring and drainage waters and in some plants. Elaborate experiments have proved that the production of nitrates in the soils from nitrogenous compounds is chiefly due to the action of life. The other source being electrical discharges.

During every rain, a part of the fall flows off as surface water: a considerable portion creeps through the soil and reappears

in springs: but a small portion starts on a more extensive underground journey, during which it often penetrates to great depths, traverses hard and soft rocks alike, and is ever present in the crevices of the rock. This cold water, falling from the clouds, is free from mineral impurities and has little solvent power except for the most soluble minerals, such as salt, gypsum or calcite. As it passes through the soil and the surface coating of vegtable matter, certain acids and gases are absorbed. These give to the water an increased solvent power, and as it descends it may eventually become so strongly acid, or so alkaline, that even the most insoluble substances are taken into solution. The temperature of the earth progressively increases as the depth is increased, and hence water at not inconsiderable depths attains a temperature often quite high, so that its power as a solvent is vastly increased. We may then expect that waters derived from great depths, viz. artesian wells, contain a large amount of mineral matter in solution, while those from springs and surface wells would contain a low percentage of such ingredients. What the composition of the mineral substances held in solution shall be, is determined by the character of the soil and rock through which it has traveled.

Here in Illinois the rocks are in general quite soft, being composed principally of lime-stones, sand-stones, clays and shales to a depth of two thousand feet and it is to be expected that water penetrating such material would virtually be loaded with a considerable portion of impurities. It is thus impossible to obtain any water, free from mineral matter, that has once passed into the soil.

Upon evaporation the entire matter is deposited in the solid state.

The causes of incrustation exist in the mineral constituents of the water.

Calcium carbonate is a dimorphous substance crystallizing both as rhombohedrons and rhombic prisms. It crystallizes from cold solutions and as the latter from hot solutions. In pure water the solubility of the carbonate ranges from two to three grains per gallon, decreasing rapidly as the temperature rises; but when the water contains carbon dioxide, the solubility greatly increases. When carbon dioxide is passed into a solution of calcium hydroxide the carbonate is precipitated.

$$Ca(OH)_2 + CO_2 = CaCO_3 + H_2O.$$

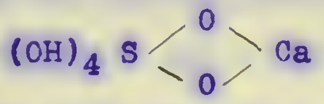
If, however, the stream of gas is allowed to pass long enough the precipitate is redissolved and the solution again becomes clear. It is evident then, that the $CaCO_3$ is soluble in water containing carbon dioxide. The soluble salt formed by this treatment is the acid carbonate having perhaps the formula,

$$HO - OC - O - Ca - O - CO - OH.$$

This bicarbonate is very unstable, for on heating the solution, the carbon dioxide is expelled and the normal carbonate is again precipitated. Hence waters may be softened by boiling to expel the carbonic acid.

Calcium sulphate occurs most frequently in nature as gypsum, crystallizing with two molecules of water, in the monoclynic system. ($CaSO_4 + 2H_2O$.) It is probably derived from the normal

acid having the following constitutional formula,



It is somewhat soluble in hot and cold water, the solubility slightly decreasing with the temperature; at 95° F. 178 grams of the sulphate can be dissolved in a gallon of water and at 212° F. or in boiling water 150 grams are dissolved in the same amount. At a temperature of 303° F. which corresponds to a pressure of 70 pounds, the sulphate loses nearly all its water and forms a powder, which has the power of taking up water of crystallization and forming a very solid substance. Heated above 392° F. (200° C.) gypsum loses all its water and the product combines with water only with great difficulty. Hence the higher the temperature to which the gypsum is subjected the greater the difficulty with which it combines with water. At ordinary temperature when brought in contact with a soluble carbonate, the calcium sulphate is decomposed, insoluble $CaCO_3$ being formed.

$$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4.$$

Advantage is taken of this property to remove the $CaSO_4$, in a water, by the addition of Na_2CO_3.

Magnesium carbonate crystallizes in the same forms as $CaCO_3$, with three or five molecules of water under favorable conditions. It is practically insoluble in pure water but like calcium carbonate it dissolves in water containing carbon dioxide. On boiling the solution, the carbon dioxide is expelled and $MgCO_3$ is deposited.

Further heating will produce another decomposition, carbon dioxide is again driven off and magnesium hydroxide results.

$$MgCO3 + H_2O = Mg(OH)_2 + CO_2.$$

It has practically the same properties as calcium carbonate, in regard to solubility under conditions of high heat and pressure.

Magnesium sulphate crystallizes in large rhombic prisms with $7H_2O$ from diluted solutions: but in small needle-like crystals, if deposited rapidly from a concentrated solution. It is quite soluble in water, 125 parts of the sulphate dissolving in 100 c.c. of water at ordinary temperatures. The solubility increases slightly when the temperature is increased. Six molecules of water can easily be driven off at a low heat, but a temperature of 200° C. is necessary to drive off the last molecule.

Ferrous carbonate crystallizes in forms similar to those of calcite. It is slightly soluble in pure water and like calcium and magnesium carbonates dissolves with ease in water containing considerable carbon dioxide, forming the bicarbonate. Boiling, removes the carbon dioxide and the carbonate is deposited. In contact with air this ferrous carbonate is quickly oxidized and ferric hydroxide is produced; ~~which~~ when a soluble carbonate is added to a solution of a ferric salt, ferric hydroxide and not ferric ferric carbonate is precipitated. This hydroxide is stable in the presence of carbonic acid.

Silicon dioxide occurs both in the crystalline and amorphous state. Quartz is a form of the former condition, crystallizing in (the

hexagonal system. Sand, flint, agate, and chalcedony are examples of the amorphous silica. Very little silica is dissolved by pure water, no matter what the temperature of the water may be: but the solubility is greatly increased by the addition of acid gases and then heat to the water. The greatest source of silica in the mineral matter of a water is due to the presence of normal silicic acid $Si(OH)_4$. This is very soluble in water but at high temperature two molecules of water are driven off and the insoluble silica deposited.

$$Si(OH)_4 = SiO_2 + 2H_2O.$$

The alkalies contained in solution are in nearly all cases sodium and potassium sulphates, carbonates and chlorides. They arise from the decomposition of complex feldspars and are very soluble in hot and cold water, the solvent power of the water increasing as the temperature rises. They are not incrusting substances and are seldom found in the boiler scale. However they are mechanically carried down with the other substances, their presence in the scale being thus accounted for.

These minerals, $CaCO_3$, $MgCO_3$, $CaSO_4$, $MgSO_4$, Fe_2O_3 and SiO_2 are all incrusting substances and it is evident that waters containing a large amount of them, will yield a correspondingly large amounts of scale. As the process in the boiler is one of evaporation, theory would have it that nothing leaves the boiler but pure water in the form of steam; the solid matter remaining to form the scale. The conditions are just ripe then for the decomposition of the

[illegible]

[illegible]

[illegible]

[illegible]

solid matter, the ~~intense~~ heat expelling the carbon dioxide from the water, precipitates the normal carbonates of calcium and magnesium, greatly increases the insolubility of the Ca sulphates, throws down the oxide of iron and the loss of water by the silicic acid precipitates the ~~the~~ silica upon the flues, backheads, etc. Here ~~thy~~ they are cemented together in a hard mass, especially if magnesium hydroxide and calcium sulphate are present, and are baked on the flues, etc. as scale. Besides the dissolved salts there are, in most waters large quantities of mechanical impurities, such as earthy matter held in suspension which also becomes baked on as scale. All the scale formers accumulate on the flues, etc. often to the thickness of one-fourth to one-half an inch or much more and being poor conductors of heat, the efficiency of the boiler is greatly reduced. Owing to the poor conductivity of the scale thus formed, the boiler plates become overheated, that is, red hot, and thus are soon destroyed. If, in an overheated boiler, a crack should be formed in the scale, allowing the water to come in contact with the red hot iron, an explosion might arise, as a result of a too sudden generation of steam.

As to external corrosion, one source is, supposedly, the presence of sulphur in the coal employed, which especially in the Mississippi Valley is present in considerable quantity. The action takes place mainly at night, or when the boiler is not in use. Soot collects upon the flues, and, due to the cooling of the pipes becomes moist, takes up sulphur dioxide produced by the burning of

the sulphur in the coal. The sulphur dioxide is gradually oxidized into trioxide, which with the moisture present immediately forms sulphuric acid. This at once attacks the iron. Another cause of external corrosion is supposed to be leakage: it being claimed that even "a very small leakage will destroy the plate from the outside". This theory is in accordance with the statement: that iron is not attacked by pure dry oxygen, but is immediately attacked thereby in the presence of moisture. Upon reaching the outside, the water at once aids the oxygen of the air and very active oxidation at once sets in.

The part which water plays for boiler purposes is of the greatest importance. It is not only interesting to scientists in a general way but it is a subject which interests deeply all owners and users of steam boilers. The great extent to which boilers are used and the many different purposes to which steam is put renders it almost a positive necessity that only the best water be used in steam boilers.

Impure waters for boiler purposes may be divided up as follows:

1. Those that corrode
2. Those that form scale
3. Those that both form scale and corrode
4. Those that throw out their constituents in form of sludge.

Mud or sludge, while it is a source of trouble to the boiler owner, gives less anxiety than incrustation or corrosion. The greatest evil lies in those river or creek waters that contain a great deal of sediment as sand, mud or clay. This sediment, though floating around in the water when the boiler is active, settles out as soon as it cools and circulation stops, forming a coating on the boiler plate which bakes on under subsequent heating and forms a solid scale much resembling scale and incrustation. The evils resulting from sludge may be greatly averted by a judicious use of the "blow off". (7)

The other evil, corrosion, is one which very few boilers are free from and may appear in the form of general corrosion or "incrusting" over the entire surface, or in "pitting". It is an evil which is a source of great anxiety; causes trouble, delay and not infrequently danger to those in charge. There is something mysterious about corrosion in some boilers because it acts so rapidly.

A "Boiler Commission" was appointed in the British Navy to investigate and they brought forth these theories for corrosion:-

"Galvanic action". Due to hypothesis that an infinite number of galvanic circles are formed by the metallic contact of the iron of the boiler with particles of copper or brass from tubes, etc., which have been carried into the boiler with the feed water. This theory is unteneable however, since the copper, if present, would settle out to the bottom and cause more corrosion there than

at any other place, but such is not the case. Besides corrosion goes on in those boilers that have no brass connections at all.

Another theory claims that the fatty acids produced by the decomposition of the lubricants used, dissolve the brass from tubes and thus form a solution of copper in the boiler. But rarely if ever is there any copper found to be present in a boiler water. On close examination these theories appear to be built on frail foundations and are not adequate to expalin corrosion.

Another theory which seems reasonable and satisfies some men is that oxidation goes on in the boiler by means of the oxygen in the water. In support of this theory they point out the fact that zinc slabs which are suspended in the boiler become converted into zinc oxide.

Some try to account for the pitting of the boiler plates by saying that the iron and steel consists of two or more different chemical compounds, one of which is electro-negative to the other. In a boiler the hot water more or less saturated with chemical compounds, is the exciting liquid, and the electro-positive parts of the boiler plates are quickly worn away.

The most important effects of corrosion are the added expenses attached to the running of the boiler and the dangers connected with it.

Boilers, steam pipes, and tubes which undergo corrosion have to be replaced by new ones after a short time or a terrible explosion is likely to result when least looked for, causing a great loss of life and property.

Now in order to avert as far ~~as far~~ as possible the various evils connected with the use of waters in boilers, the prime requisite is the use of the purest waters obtainable. There is generally a great difficulty experienced by owners of steam boilers in judging of the quality of waters accessible . It is acknowledged as the height of foolishness to attempt to estimate a water's purity by its appearance. The only correct as well as the only satisfactory way to determine the quality of a water is by having a complete chemical analysis made, and this is all the more important to those who have the choice of the use of two or more waters, since two waters from the same locality may differ widely in their chemical composition.

In making a mineral analysis of a water, besides aiming at the two requisites, accuracy and speed, the analyst should use such ~~a~~ methods of analysis that when he has finished and has the complete data, he has a correct idea of the composition of the water and can say with confidence just how that water will conduct itself when used in a boiler. ¶

The data derived from the ordinary method of analysis of waters is not sufficient to enable the analyst to base any judgment as to the properties of that water when used for boiler purposes. This is true because of the fact that no attention is paid to the changes that the water undergoes when subjected to the high pressure and heat inside a boiler. The total ingredients are determined without regard to their form.

Take a water for example which contains according to the analysis the following ingredients:

	gms. per Liter	Grains per U.S. gal.
Cl	0.0230	1.401
SO_3	0.0834	4.848
CO_2	0.1270	7.429
Na_2O	0.0435	2.529
CaO	0.1476	8.581
MgO	0.0441	2.614
SiO_2	0.0244	1.418
FeO	0.0027	0.156

Now there is no arbitrary rule whereby the ingredients are combined to make up the different salts, but the authorities agree very closely as to what order should be followed in doing it.

Professors Balton and Cairns both use the same order of calculation which may be outlined thus:-

Combine Cl as NaCl
Combine excess Na as Na_2SO_4
Combine excess Cl as $MgCl_2$
Combine excess SO_3 as $CaSO_4$
Combine excess Ca as $CaCO_3$
Combine excess Mg as $MgCO_3$.

Following out that order of combination we have as the composition of the water containing the above ingredients :-

	gms. per L.	Grains per U.S. gal.
NaCl	.0381	2.215
Na_2SO_4	.0545	3.168
$CaSO_4$	.0946	5.500
$CaCO_3$	.1964	11.418
$MgCO_3$	.0945	5.497
SiO2	.0244	1.418
FeO	.0027	0.156

Now what does this series of combinations represent? No one would claim that that is absolutely the exact composition of the salts; that no other arrangement of combinations between bases and acids is possible. No one can say that all the chlorine present is combined as sodium chloride or that the magnesium is all present as magnesium carbonate. On the other hand it has been mathematically and chemically demonstrated that in a mixture of salts like the above, every base present is combined with more or less of every acid present.

The above calculations are evidently based on the arrangement which the salts would take when brought to dryness from a solution, and for simplicity or convenience we assume that those are the arrangements which the salts take when in solution.

Now if we assume this series to be the correct ~~correct~~ set of combinations what evidence would it afford regarding the character of the water for boiler purposes? None of the combinations are such as fall within the class of corrosive substances. The total amount of scale forming ingredients is 23.96 grains per U. S. gallon. This

by reference to the scale adopted by the Union Pacific railroad would be classified as a "good" water. As a matter of fact this same water in use proves to be a seriously corroding as well as scale forming water and the question is at once raised as to the source of error in our method of diagnosis.

It has been proven by investigation that waters drawn from steam boilers after prolonged concentration and heat showed some rather unusual and unlooked for interchanges and decompositions of the salts in solution.① Hence the theory suggests itself that the above plan for combining the constituents found may be in error when we assume that to be the method of combination after prolonged use in the boiler. Following along this line of reasoning may it not be that under the concentration of the sodium chloride and sulphate that must naturally exist, the solubility of the magnesium carbonate is so increased that a double decomposition is effected, resulting in the formation of magnesium chloride at the expense of the sodium chloride, thus necessitating a shifting of some of the acid radical of the calcium sulphate, giving as final products; magnesium chloride sodium sulphate and calcium carbonate in place of sodium chloride, sodium sulphate, calcium sulphate, magnesium carbonate and calcium carbonate. This decomposition may be represented by anequation like this:

$$2NaCl + 2Na_2SO_4 + 2CaSO_4 + 2MgCO_3 = 3Na_2SO_4 + MgCl_2 + 2CaCO_3 + MgSO_4.$$

These combinations are further corroborated by a method of analysis devised for the purpose of duplicating the processes in

the boiler, namely; by evaporating the water nearly to dryness and separating the soluble part from the insoluble part by careful and thorough washing, and analyzing each portion separately. By this same method thissame water gives the following data for the soluble part:

	gms. per L.	Grains per U.S. gal.
$MgCl_2$	.0308	1.79
$MgSO_4$	.0381	2.20
Na_2SO_4	.0995	5.76

and the following for the insoluble part:

	gms. per L.	Grains per U.S. gal.
SiO_2	.0244	1.41
FeO	.0027	0.15
$CaCO_3$	.2635	14.38
$MgCO_3$	.0232	1.35

Thus we see again that the equations are corroborated as shown by the analysis of the soluble part. (Sc. Am. Sup. 3:1334).

The method of analysis of waters used most in this investigation will be detailed here.-

$\underline{SiO_2}$. In ordinary cases one liter of the water was acidified with hydrochloric acid and evaporated to dryness upon the water bath in a platinum dish, then heated in an air bath at 180° for an hour or until the masswas completely dry and brittle. Now moistened the residue throughout with a little concentrated hydrochloric acid, added thorty to forty c.c. of water and after digesting upon the water bath for a few minutes filtered off the silica by

use of an ashless paper, and after washing completely ignite and weigh as SiO_2. Treat with HF and determine the SiO_2 from the loss in weight. Notice that calcium sulphate is frequently found in waters and as this substance dissolves slowly it is necessary to be especially careful that none of it remains with the silica. If some of it is so left it will be found after volatilizing the SiO_2 by means of HF and it must be dissolved in HCl and added to the solution from which it, together with the silica has been removed. It is possible that a little sulphate of barium or strontium may be found at this point; if iron is present in the residue it will be necessary to fuse with $KHSO_4$, dissolve in dil. sulphuric acid and water and add to original solution.

FeO and Al_2O_3. To the mixed filtrate and washings from the silica add a little bromine water and boil for 10 or 15 minutes to ensure complete oxidation of the iron present, then add 25 c.c. of ammonium chloride solution and a distinct but not great excess of ammonia: boil vigorously for five minutes, allow to settle, filter and wash thoroughly with hot water: ignite and weigh as Al_2O_3 and Fe_2O_3. Iron and aluminium was not separated in all cases, but in those in which they were separated the following method was followed: Fuse the weighed residue with 8 times its weight of $KHSO_4$, dissolve in water and dilute sulphuric acid and after reduction by use of Jones Reductor, determine iron volumetrically by potassium permanganate solution. Calculate to FeO. The amount of FeO calculated to Fe_2O_3 subtracted from the above weight gives as differ-

ence the weight of Al_2O_3.

CaO. Concentrate the filtrate and washings from the precipitation of hydroxides above to about 200 c.c. and precipitate hot with ammonium oxalate and ammonia. Calcium determined volumetrically thus: Dissolve the precipitate of calcium oxalate, which has been washed free from all soluble oxalates, on the filter with twenty-five to forty cubic centimeters of hot dilute sulphuric acid. Heat the solution a little below the boiling point and titrate with a standard solution of potassium permanganate. This method found to give very satisfactory results and when the amounts of calcium oxalate are very small the method is very rapid.

MgO. Filtrate and washings from the calcium oxalate concentrated to about 200 c.c. and magnesium precipitated as the phosphate. Wash, ignite and weigh as $Mg_2P_2O_7$. Calculate to MgO.

Estimation of sulphuric acid and the alkalies.

Take the filtrate from the silica above, heat to boiling and add a few drops of barium chloride solution and stir well and estimate the sulphuric acid present as $BaSO_4$. Calculate to SO_3. Filtrate from the barium sulphate concentrate, treat with slight excess of alkali free $Ba(OH)_2$ to precipitate magnesia, boil, filter, and proceed with the purification of the alkalies by means of ammonium carbonate and ammonia as per Fresenius p. 427, and when you are sure that the chlorides are in a state of perfect purity, ignite and weigh.

The chlorine is determined volumetrically with a standard solution of silver nitrate.

The whole method of analysis is as has been stated, satisfactory and with a little practice and care becomes very rapid. It is open to small errors and some of its operations are long, and on account of these facts one is liable to look upon the method as a tedious and patience trying job, but at the same time the method posesses a great many advantages, the most important of which is accuracy.

Another method which was used to some extent in this work gave results very satisfactory. It differs from the one I have described in the estimation of the alkalies. The magnesium is precipitated with ammonium phosphate instead of sodium ammonium phosphate, a known quantity being added. The precipitate is filtered and washed and after boiling off the NH_4OH an equal number of c.c. of manganese chloride of such a strength as to be equivalent volume for volume of the ammonium phosphate is added to remove excess of phosphoric acid. Filter and wash well. Remove excess of manganese with hydrogen peroxide and strong ammonia. Filter and wash. Dissolve the precipitate in hydrochloric acid and reprecipitate and add filtrate to previous one. Evaporate to dryness in a platinum dish and ignite. Weigh and dissolve in a little water, evaporate, ignite and weigh to constant weight. Make a separate determination of SO_3 in the usual way taking 250 c.c. of the original water for the determination.

NOTE. It is necessary to redistill the hydrogenperoxide as it contains some phosphoric acid. For accurate results the manganese precipitate must be redissolved and precipitated again in order to get all the alkalies present.

This method proved to be a little more rapid than the previous one.

ANALYSES OF WATERS.

A considerable number of waters were analyzed according to the above method which has for its basis the separation of the soluble part or the alkalies by the barium hydrate method.

The analysis of the water drawn from the Illinois Central deep well at Champaign according to this method gives the following:

SiO_2	1.07	grains	per	U. S. Gallon.
$Fe_2O_3+Al_2O_3$	.25	"	"	"
$CaCO_3$	11.71	"	"	"
$CaSO_4$	2.65	"	"	"
$MgCO_3$	2.62	"	"	"
Na_2CO_3	4.95	"	"	"
NaCl	.13	"	"	"
	23.38			

The total scale forming material is 18.3 grains per gallon which, according to the classification adopted by the Association of Railway Chemists, is classified "fair".

The classification is as follows:

Below 15	grains	per	U. S. gallon	good
15-20	"	"	"	fair
20-30	"	"	"	poor
30-40	"	"	"	bad
Over 40	"	"	"	very bad.

The amount of the sodium carbonate is rather high and under use in the boiler we would assume that it would precipitate

all of the lime and magnesia as carbonates forming a loose flaky mass instead of a scale or crust. The analysis of the water drawn from the boiler verifies the statement.[15]

Analysis of the water drawn from the Tolono city well, 135 feet deep gives the following:-

SiO_2 --------- 1.42 grains per U. S. gallon.
Fe_2O_3, Al_2O_3 0.17
$CaCO_3$ -------- 8.74
$MgCO_3$ --------- 6.33
Na_2CO_3 ------- 4.83
NaCl ------- 0.38
21.87

The same conslusion would be drawn from there data as those from the analysis of ~~the~~ from the champaign water, the magnesia and lime being precipitated by the sodium carbonate present.

The results from these waters show that the conclusions to be drawn from this method, when properly carried out are in the main ~~perfectly~~ correct.

All the analyses of waters undertaken in this work will be tabulated on the following pages.

Results in Grains per U.S. gal.	Tolono deep well	Champaign deep well	Linton Ind. Elec. L. Co's. Plant.	MtPulaski Ills.	Lynn, Ind.
SiO_2	1.42	1.07	0.99	1.18	0.87
Fe_2O_3 + Al_2O_3	0.17	0.25	0.27	1.39	4.52
$CaCO_3$	8.74	11.71	3.28	9.75	14.25
$CaSO_4$		2.65		1.97	
$CaCl_2$					
$MgCO_3$	6.33	2.62	0.30	6.01	5.42
$MgSO_4$					
$MgCl_2$					
Na_2CO_3	4.83		25.83		1.97
Na_2SO_4		4.95	2.73	1.88	2.05
NaCl	0.38	0.13	2.66	6.65	0.76
Scale forming	16.66	18.30	4.84	20.30	25.06
Total Solids	21.87	23.38	36.06	28.83	29.84

Results in Grains per U.S. gal.	Arcanum, Ohio.	Durbin, Ohio.	Troy, Ohio.	Maxwell, Ind.	New Castle, Ind.
$SiO2$	0.19	1.21	1.24	1.18	1.53
Fe_2O_3 + Al_2O_3?	3.49	1.12	1.38	0.99	0.75
$CaCO_3$	11.18	8.37	14.30	21.01	22.74
$CaSO_4$					
$CaCl_2$					
$MgCO_3$	6.24	7.04	19.33	5.78	17.32
$MgSO_4$					
$MgCl_2$					
Na_2CO_3	0.17	0.71	3.32	5.87	4.38
Na_2SO_4	1.48	trace	4.16	none	trace
$NaCl$	1.43	0.01	0.84	1.92	1.43
Scale forming	21.10	17.74	36.25	28.96	42.34
Total Solids	24.18	18.49	44.57	36.75	48.15

Results in Grains per U.S. gal.	Springfield, Ohio.	Tap Water Urbana, Ills.	Brick Yard Water Urbana, Ills.	Sadorus, Ills.	Ivesdale, Ills.
SiO_2	0.79	1.14	0.31	0.80	0.87
Fe_2O_3 & Al_2O_3	0.63	0.77		0.11	0.11
$CaCO_3$	9.08	11.16	7.09	22.87	9.71
$CaSO_4$			9.15	1.13	0.63
$CaCl_2$					
$MgCO_3$	6.42	6.44	0.14	3.10	3.60
$MgSO_4$			4.82		0.34
$MgCl_2$					
Na_2CO_3	2.02	3.57	5.60		11.26
Na_2SO_4	3.64	0.92	18.06	2.22	1.89
NaCl	0.96	3.13	13.06	5.95	35.31
Scale forming	16.92	19.51	45.17	28.01	15.26
Total solids	23.54	27.13	58.23	36.18	63.72

A considerable amount of time and study was spent upon the mechanical separator is use at Robinson's Mill Urbana, Ills. The water used in the boiler is from a deep well of 110 feet. The boiler has been in constant use for a year and has never been cleaned and no appreciable amount of scale is present in the boiler. The separator acts more as a settler, the impure water from the boiler passing through it and all the heavy matter settles in the separator and is drawn off every two hours or so while in use.

Analyses were made of the original water, of the water from the boiler and from the separator after filtering. The results of these analyses will be found on following pages.

Original Water from Robinson's Mill.

SiO_2	1.12
Fe_2O_3	1.03
$CaCO_3$	10.80
$MgCO_3$	6.15
Na_2CO_3	7.69
Na_2SO_4	1.82
$NaCl$	0.29
$CaSO_4$	----
$CaCl_2$	----
$MgSO_4$	----
$MgCl_2$	----
Scale forming	19.10
Total Solids	28.90

Filtered Water from Separator, Robinson's Mill.

SiO_2	0.16
Fe_2O_3 + alum	0.59
$CaCO_3$	1.86
$CaSO_4$	----
$CaCl_2$	----
$MgCO_3$	trace
$MgSO_4$	----
$MgCl_2$	----
Na_2CO_3	7.89
Na_2SO_4	1.34
NaCl	0.29
Scale forming	2.61
Total Solids	12.13

Water taken from the Boiler, Robinson's Mill.

SiO_2	1.22
Fe_2O_3 Al_2O_3	1.62
$CaCO_3$	12.88
$CaSO_4$	----
$CaCl_2$	----
$MgCO_3$	5.24
$MgSO_4$	----
$MgCl_2$	----
Na_2CO_3	5.68
Na_2SO_4	2.52
$NaCl$	2.44
Scale forming	20.96
Total Solids	31.60

SCALES.

Several scales from various places were analyzed by a method similar in many respects to the one used for boiler waters.

They were dissolved in HCl and method of analysis carried out as in a water.

Free iron was present in one scale. This was determined by folding a piece of paper over the end of a magnet and in this way remove all the free iron from a known sample. The object of the paper is to keep the free iron from the magnet, because if you do not do this it will be almost impossible to get all the particles from the magnet. By using a paper on the magnet when you have collected all the iron possible transfer to a beaker and slide the magnet out of the paper and the iron will immediately drop into the beaker.

Considerable difficulty was experienced in pulverizing the scale containing free iron.

Results on following pages.

Boiler Scale, Heating Plant, University of Illinois.

SiO_2	11.37 %
Fe_2O_3	15.69 %
$CaCO_3$	53.40 %
$CaSO_4$	1.41 %
$MgCO_3$	15.02 %
Free Iron	1.82 %
Moisture	2.83 %
Total	100.13 %

Boiler Scale taken from a traction engine.

SiO_2	8.60 %
Fe_2O_3	1.00 %
$CaCO_3$	77.16 %
$CaSO_4$	2.32 %
$MgCO_3$	10.44 %
Moisture	0.62 %
Total	100.14 %

In conclusion I would say that waters, whose composition are unknown can be treated successfully by any preventative, is out of the question, and the struggling mechanic must call to his aid the chemist, whose scientific knowledge can alone improve the situation.

The use of poor waters on any portion of a railroad is a source of great annoyance to the engineer, of whom it requires a longer time to get up steam, because of the deposition of scale on the flues of the engine; proper circulation of the water in the boiler is interfered with; a greater consumption of fuel also results, 60 % more for 1/4 inch thickness of scale, 150 % more where the deposit is 1/2 inch thick.

Or, if there is no scale formed and the action of the water is corrosive, and chews the plates and crown sheets, weakens the boiler materially, causing leakage or placing it at a predisposition to explosion.

A loss of $100.00 to 150.00 per day is incurred by the idleness of a locomotive; while again the expense of renovating the boiler every three or four months, which is in itself quite an item, requiring four men two or three weeks to perform the wrok.

Also the destructive action of superheating the boiler, which can not be avoided with cases of incrustation.

And lastly the inconvenience caused from these sources by having fewer locomotives to operate during those seasons when shipments are heavy and all engines are greatly in demand, justify me

in saying that the subject in hand should be given much attention.

* * *

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